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Dalhuisen, J.M.; de Groot, H.L.F.; Nijkamp, P.

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## **SERIE RESEARCH MEMORANDA**

The economics of water  
a survey of issues

Jasper Dalhuisen  
Henri de Groot  
Peter Nijkamp

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# The Economics of Water

## *A survey of issues*

Paper prepared for special issue of the  
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by

Jasper M. Dalhuisen, Henri L.F. de Groot and Peter Nijkamp<sup>1</sup>

Free University of Amsterdam and Tinbergen Institute

Department of Spatial Economics

De Boelelaan 1105

1081 HV Amsterdam

The Netherlands

E-mail: hgroot@econ.vu.nl

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### *Abstract*

This paper provides a survey of central issues addressed in research and policy on the economics of water. The paper starts with a discussion of water, its supply and demand, and the institutions that bring supply and demand together. Special attention is paid to the specific features and desirability of various price and rate structures of water. We also deal with several market failures that justify government intervention, while we finally discuss some of the policy issues that arise in water management.

Keywords: water management, water demand and supply, water-pricing

JEL-codes: H0, Q2, Q3, R2

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# The Economics of Water

## *A survey of issues*

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### *Abstract*

This paper provides a survey of central issues addressed in research and policy on the economics of water. The paper starts with a discussion of water, its supply and demand, and the institutions that bring supply and demand together. Special attention is paid to the specific features and desirability of various price and rate structures of water. We also deal with several market failures that justify government intervention, while we finally discuss some of the policy issues that arise in water management.

## 1. Introduction

The importance of water as the most fundamental constituent of life needs no explanation. It was, it is, and it will remain a vital element for the survival of the human race. It is within as well as around us in seemingly abundant amounts. Nevertheless, severe problems with its provision are as old as mankind. Some of the central problems have neatly been summarized by Ponting (1991, p. 346) as follows: *'For thousands of years the chief struggle was over sanitary arrangements and the main challenge was to obtain unpolluted water supplies. These problems became even more acute as human numbers and urban life increased, but widespread industrial production and the use of new technologies introduced new pollutants and brought new risks to human health and the environment'*.

Problems with water supply stem from various sources. Increased population led to an increased pressure on the limited amount of fresh water, which constitutes only about 0.4 % of total water available in the world.<sup>1</sup> Secondly, concentration of people in locations which over time were further and further removed from water sources resulted in a need for

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<sup>1</sup> Most water stems from seas and oceans and is saline. Technologies to desalinate this water are required to transform this water into potable water. Up to now, these technologies have been considered too costly. However, the increased pressure on fresh water supplies may change desalination into an economically attractive option in the near future.

networks transporting water from source to user. Thirdly, industrialization and increased population have tremendously increased the pollution of water, urging for cleaning and costly water treatment facilities. Finally, technological developments have in the 20th century resulted in a situation where in the industrialized world almost all houses were connected to the public water network, resulting in a drastic increase in per capita water demand. These developments have led to a situation in which almost everywhere in the world serious problems exist with supplying a sufficient amount of clean water, whereas in several places there are also problems with the absolute amount of water available for consumptive use in at least particular seasons. These developments have called for a good management of water resulting in a sustainable use of water. In defining sustainability, we follow the 'Brundtland definition' that defines sustainable development as '*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*' (World Commission on Environment and Development, 1987).

In this survey, we will consider water as an economic good and discuss how policies can be employed to guarantee sustainable use of water. To achieve this aim, we will first discuss the elementary characteristics of water. Next, we turn to the demand and supply of water and discuss the pricing of water as an economic good. We conclude with a discussion of the policy alternatives that can be employed to guarantee and improve the sustainable use of water. By opting for this approach, we explicitly recognize that an integrated study of both supply and demand determinants is crucial for a fruitful study for the issues at hand (see, e.g., Baumann et al. (1998) for a similar argument). Furthermore, we also argue that it is useful to study the economic characteristics of water. It has often been argued that water is such a specific good with such unique characteristics that it is of little use to study the economic aspects of water. Although it may be true that water has some characteristics that distinguish it from other goods, these characteristics can well be tackled within economic theory. An economic approach to water supply and demand may contribute to a better management of water and to its sustainable use.

## **2. Water as an economic good**

This section starts with a discussion of the main characteristics of water. Next, the characteristics of the demand for and supply of water are reviewed. In principle, the market mechanism could be used to bring demand and supply together. However, there are several market failures that justify government intervention. The next question then is how government intervention should exactly be formulated from a socially optimal point of view.

Various pricing and allocation mechanisms that currently exist are discussed along with their respective advantages and disadvantages from a social optimality point of view.

## **2.1 Basic characteristics of water**

A crucial characteristic of water from an economic point of view is that the assignment of property rights is difficult. Water falls from heaven, and flows and evaporates with no regard to any boundary, be it private, state, or national. Water is therefore to a large extent non-excludable. It is, however, rival and thus cannot be categorized as a public good. Instead, it is often labeled as a common pool resource, meaning that there is a finite amount that must be shared in common over a variety of uses and over geographic areas. The classical tragedy of the commons arises, since users are likely to ignore the effects of their actions on the pool when pursuing the self-interest. A second important characteristic is that the renewal of water is both stochastic and seasonal, implying uncertainty in its supply. Periods of intensive droughts may for example be alternated by periods of heavy rainfalls. Given the constant need for water, this poses several problems. It calls for investments in infrastructure that enable us to store and regulate the supply of water. A third important characteristic of water is that it cannot be considered as a homogeneous good. There are all sorts of qualities, ranging from surface water to drinking water, each with their own supply and demand characteristics (to which we will return in Section 2.2). In addition, quality may vary substantially, both in space and in time. Again, this calls for investments aimed at guaranteeing minimum quality standards for the various uses of water.

## **2.2 Characteristics of demand and supply**

### **2.2.1 Demand<sup>2</sup>**

The demand for water can be split up in several components and in several ways. To get a good impression of the total demand, its composition, and its future development, these classifications are of utmost importance. One distinction is between demand for productive

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<sup>2</sup> In this paper, we abstain from specific issues related to the demand for water from the agricultural sector, and focus mainly on household and industry demand. For an overview of agricultural water demand, we refer to the OECD (various sources). The specificity of agricultural demand (as well as demand of large industrial firms) resides, among others, in the fact that there is much self-provision by own extraction and cleaning of water. This poses special problems of pricing and assigning property rights which are beyond the scope of this survey.

and consumptive purposes. Within these categories subdivisions can be made between water-intensive and water-extensive producers, low- and high-income households, households with and without gardens, etc. Failure to take into account developments of, for example, household income, household composition, industrial mix, the housing stock, and the price of water will result in forecasts of water use that may be strongly mistaken with serious and potentially damaging consequences, given, for example, the large extent of irreversibilities associated with investments in the water supply network.

To get a first impression of water use, one can look at its variability over regions, family types, housing characteristics, industrial composition, and income (see for example Achtenribbe (1992), Baumann et al. (1998) and OECD (1998)). This evidence reveals various interesting aspects of water use. First, a substantial part of total water use is made up of residential use, although there are huge variations between countries. Within the category of residential use, there are important differences between per capita use in single-family establishments and multi-family establishments (flats and apartments). The major difference being that outdoor water demand in the latter category is negligible. Thirdly, there is an important geographic variation in residential water use due to, for example, differences in temperature, degree of urbanization, but also differences in housing mix, etc. Finally, per capita use may vary substantially with age, income or family size (suggesting economies of scale in water use).

Another distinction that is of importance when studying demand for water is the distinction between various qualities of water. A natural distinction here is between water used for drinking, washing, and showering purposes (which has to be of high quality) and water used for other activities like gardening and flushing toilets (which may be of lesser quality). Estimates for the US indicate that the potable water requirement (depending on, among others, location) ranges from 11 to 60 percent of total water demand (American Water Works Association (1989)). This reveals that the largest part of water is used for activities that do not require water of potable quality. Unfortunately, there is little known on consumer demand for different qualities of water. This lack of insight is mainly due to the fact that water is usually supplied as a homogeneous good (at least for residential use). Therefore, demand for water of differentiated quality remains largely unnoticed. We will return to this at a later stage in the paper when we discuss the desirability of a system of dual piping.

To get a better insight in how demand will evolve over time and how various economic agents will respond to, for example, price changes, knowledge is required on for example price and income elasticities of the demand for water. This knowledge is particularly important for policy-makers aiming at influencing demand by price measures. In Appendix A, we give an overview of how these elasticities can be derived from theoretical models of

producer- and consumer behavior. In this Appendix, some background information is also given on how these elasticities are usually estimated. The evidence on demand elasticities is far from conclusive. Table 1 gives an overview of price and income elasticities that have been found in the literature and some of the details of the respective studies. We restrict our attention to estimates applying to OECD-countries. The Table is deliberately far from complete. Attention has been restricted to the most often cited studies. For an extensive overview of the results for the US, we refer to Baumann et al. (1998; Table 2-5).<sup>3</sup> The general conclusion which we can draw from Table 1 is that the evidence on price- and income elasticities derived from econometric studies is scattered. Nevertheless, some conclusions seem to be justified. First, the vast majority of studies indicates that both price and income elasticities are smaller than one (in absolute terms), but significantly different from zero.<sup>4</sup> Secondly, elasticities depend on the season, and the goal water is used for (in-house versus ex-house demand, industrial versus domestic demand).

< Insert Table 1 around here >

Besides the econometric studies measuring price and income elasticities, there is other evidence from which we may get some insight in how consumers will change their demand in response to price and income changes. There is, for example, evidence on water savings resulting from metering and charging by volume, and consumption effects from tariff structure changes (OECD (1998; Tables 25-27)). We can conclude from these studies that (i) metering is effective in reducing demand for consumptive uses, and (ii) consumers reduce their peak-demand in response to the introduction of seasonal rates and increasing block tariffs.

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<sup>3</sup> We will not discuss the details of all these studies and their relative strengths and weaknesses. Some remarks are in place, however, on issues that arise in estimating the elasticities. First, there is no general agreement on how the estimation should be done. It seems by now well established that estimation by OLS yield biased estimates. But no generally agreed upon alternative is yet available. Secondly, studies differ in the detail in which various categories of demand have been distinguished. Some studies distinguish between for example indoor and outdoor demand, the latter being more likely to be elastic than the former (see Appendix A for a further discussion of these issues). Thirdly, studies may differ with respect to location, time span, variables that have been controlled for (like temperature), etc.

<sup>4</sup> It is, for instance, noteworthy that most Dutch consumers are unaware of both the price of water and their water bill. The responsiveness to price changes is puzzling, unless consumer reactions are enhanced by a growing awareness associated with, for example, information campaigns surrounding price reforms (an illustration is the recent discussion on the increase in VAT on water that was recently decided upon in the Netherlands).



The evidence that has been discussed so far considers water as a homogeneous good of potable quality. However, as was already pointed out previously, water is used for various purposes, each with their own quality requirements. This has some important implications. It suggests the optimality of supplying consumers with water of various qualities. Given the problems with providing different qualities, this is an option which is not often employed. Nevertheless, dual-supply systems exist(-ed) in some places. For example, in England and Wales low-quality water was supplied to some industrial firms, while in Hong-Kong and Japan sea-water was distributed to households for toilet-flushing in the mid 1970s (see OECD (1987) for more detailed overviews of existing experience). The main (technical) problem with dual piping is that it requires a transport-system which is costly to construct. In addition, there may be health dangers that prevent the introduction of dual piping in the domestic sector.<sup>5</sup> Nevertheless, it is worthwhile to consider the expected welfare effects of developing a system of dual piping. This is a topic of further research. Such a study requires, among others, knowledge on demand for water of differentiated quality. Such knowledge is hard to obtain. One obvious problem is that markets for water of non-potable quality do often not exist. Therefore, there are no data from which for example demand-elasticities might be estimated. One way to proceed might be to obtain data by asking people their willingness to pay for water of various qualities.<sup>6</sup>

### 2.2.2 Supply

There are two main sources of fresh water supply that can be distinguished. The first is surface water that consists of water in rivers and lakes. This source is to a large extent renewable. Part of it is renewed with waste-water that results from the consumption of water by firms and consumers. The other source of renewal is rainfall. An important element of a well-functioning water management system is the treatment and cleaning of waste water. In contrast with surface water, groundwater has important characteristics of a non-renewable resource. Although it is recharged to some extent, the rate of recharge is low.

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<sup>5</sup> Besides the costly construction, there are other problems. Building a second network may reduce water pressure in the already existing network which may have undesirable side-effects on quality (like faster bacterial growth). Also, the risk of cross-connection and inadvertent use should in some way be prevented for health and water quality considerations. Advantages are, among others, that non-potable water can be supplied without (additional) treatment, abandoned pipeline may be utilized to transport non-potable water (e.g., Johnson (1991)).

<sup>6</sup> In addition, non-potable water demand may likely have a low demand, as consumers simply may wish to have the best water quality that is available, independent of what it is used for.

Each source of supply has its own problems, advantages and disadvantages. We will pose a few here. Surface water is easily to obtain, but is in general of lower quality than groundwater. The quality problem has been exacerbated by pollution from agricultural, urban and industrial wastes and requires huge investments in installations for treating waste water. Supply of surface water is highly uncertain and may drop below subsistence levels in periods of drought. Reliability of surface water as a source of supply can therefore be rather low and groundwater is needed as a buffer against periods of drought. This poses issues in the optimal conjunctive use of surface and groundwater (e.g., Provencher (1995)). Groundwater, being a non-renewable resource, poses serious problems in that too quick a rate of depletion has to be avoided.<sup>7</sup>

As already pointed out in the introduction, the supply of sufficient high-quality water is no obvious task, despite its seemingly abundant availability (at least on a global scale). Problems are related to (i) temporal and geographical variation of supply, (ii) population pressure causing an ever-increasing global demand, (iii) the immobility of people concentrating in places often far away from the sources of water supply, (iv) the reduced quality of water that is globally available (see, for example, Tietenberg (1994)). These problems have been coped with in different ways in different places in the world. Common in all countries is that there is a growing awareness of these problems and that an integrated approach to supply and demand is advocated all over the world. In the remainder of this section, we will pay attention to the water industry as it exists in all advanced countries in the world. Important characteristics of these industries will be pointed out. Future studies will aim at a structured inventory and description of the various systems and their respective effectiveness.

The activities of the water industry consist of gathering, treating, transporting, storing and distributing water, as well as collecting, transporting and treating waste water. A distinctive characteristic of this industry is that it is extremely capital intensive. Huge investments have been made and will remain to be made in building dams, developing and maintaining the network used to transport water, and factories build to collect and treat water from the various sources. What makes these investments special is that they often have very

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<sup>7</sup> There is an extensive literature on the optimal depletion and pricing of non-renewable resources which we will not discuss here. This literature goes back to the classical paper by Hotelling (1931) on the 'Economics of Exhaustible Resources'. We refer here to, for example, Baumol and Oates (1988; chapter 9). Issues that arise are how the need of future generations have to be taken into account, etc.

long life times (for networks and dams over 50 years). This points at the crucial importance of correct decisions on, for example, investments aimed at extending capacity.<sup>8</sup>

In organizing the industry, several important issues arise. Considering the supply-chain as a whole, the industry should likely be considered a natural monopoly. The required investments in especially the distribution network are so large, that it is unlikely that two firms, each with their own network, can profitably operate in this industry. This calls for publicly providing at least the distribution network (or for regulation of the monopolist building and maintaining the network). However, the chain can be split into several parts and large parts do not have the characteristic of a natural monopoly. This has led to water industries over the world that differ tremendously in the relative importance of private and public organizations in the water supply function. A question that arises here is what the scope for and desirability of privatization in the water industry is. We will extensively return to this question in section 2.4.

### **2.3 *Institutions and pricing of water***

Having discussed the basic characteristics of the supply and demand of water, the focus will now be shifted towards a discussion of how supply and demand meet each other. It is here that water management explicitly enters the picture. We have to address how water is delivered and distributed over uses and users and how the needs of future generations are taken into account. The rules and institutions that define the possible actions of all the agents involved in the supply and demand enter at this stage. In this section, we will restrict attention to a positive analysis, describing the most commonly used allocation mechanisms. In the next section, the normative question on how institutions should be defined from a economically optimal point of view will be addressed. This is also the appropriate place to discuss the various advantages and disadvantages of currently used allocation mechanisms.

#### **2.3.1 Pricing of water; the theory**

In pricing water, both the level and the structure of prices have to be taken into consideration. There are at least four requirements that have to be taken into account when developing a pricing structure. First, pricing should be such that it enables the supplier of water to cover its costs. Secondly, pricing should be such that it is considered fair. Thirdly, prices should be

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<sup>8</sup> This also points at the importance of good forecasting models for water demand (*cf.* Baumann et al. (1998)).

such that they provide incentives to the users of water to use water efficiently. Fourthly, the pricing system that is used should be administratively feasible (and efficient). Each system employed in practice scores differently on these requirements. In this section, we will make these requirements more explicit, and show that they may be (partly) conflicting in various cases. In turn, various systems employed in practice are described along with their advantages and disadvantages.

*Requirement 1. Full cost recovery*

At least for the privatized part of the water industry, prices should be such that they enable the firms engaged in water supply to earn a profit (abstracting from lump sum transfers from the government to these firms). Publicly owned firms could in principle be financed out of general tax revenues (or increased government debt). The costs that at least<sup>9</sup> need to be covered consist of two parts, namely (i) variable extraction, cleaning, and transportation costs, and (ii) capital costs of installations to extract, clean and transport the water. Besides the absolute amount of money gathered, also the stability of the flow of revenue is a criterion to be taken into account, since stable revenues ease the task of financial planning and budgeting. This requirement imposes that prices should be sufficiently high and that revenues do not depend too much on variable demand (implying either counter-cyclical pricing<sup>10</sup> or a large payment that does not depend on demand). The most simple way to fulfill the requirement of full cost recovery is to engage in average cost pricing.

*Requirement 2. Equity*

Given the fact that water is a vital element for human life, every person should be able to acquire at least sufficient water to survive. An additional requirement one could impose here is that the water-bill does not account for a disproportionately large share of total income. This requirement may call for subsidizing low-income households or for prices that rise with demand (guaranteeing that the units of water essential to survive can be obtained at a relatively low price). The requirement of equity not only arises in relation to pricing within one generation, but it also arises in relation to demand of different generations. Pricing should be such that future generations that cannot currently express their needs get a fair share of the

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<sup>9</sup> There is a third class of costs, namely external costs, that we have to distinguish. We return to the treatment of external costs when we discuss the criterion of economic efficiency (requirement 3 below).

<sup>10</sup> Prices should increase when demand falls (for exogenous reasons related to, for example, the weather) and vice-versa.

scarce amount of available water. This requires prices to be sufficiently high to avoid over-pumping of groundwater and excessive pollution of water sources.

*Requirement 3. Economic Efficiency*

From an efficiency point of view, the rate structure should be such that (i) it provides incentives to efficiently use water (which requires that the price should reflect marginal costs) and (ii) it provides optimal incentives to engage in development of the system and investment in water saving technologies. This boils down to the condition that prices should equal long-run marginal social costs.<sup>11</sup> Two central issues arise here. First, it is the social instead of private marginal cost of supply that matters, which includes external costs like depletion and pollution costs. Secondly, it is the long-run cost that matters, which includes capital and operating costs associated with infrastructure facilities. The implications of a strict application of the marginal cost rule are far reaching. For example, users that are located far away from the supplier in hilly regions should pay more than users that are located in flat regions close to the supplier, users living at the tenth floor of a flat should pay more than users on the fifth floor, water use at peak hours and in summer should be relatively expensive, etc.

*Requirement 4. Administrative feasibility and efficiency*

The before mentioned requirements often imply relatively complex rate structures. There are however practical constraints deriving from administrative feasibility and efficiency. First, to make it possible, for example, to administer use (at different times of the day or in different periods of the year), different meters have to be installed. The costs associated with this may not outweigh the gains in, for example, efficiency or equity. Secondly, marginal cost pricing requires knowledge on the monetary equivalent of external costs which are often highly uncertain (if available at all). Finally, complex systems may in practice be undesirable since they are expensive and may go at the expense of transparency, limiting their usefulness for providing, for example, the proper incentives to firms and households.

Having discussed the various requirements that a pricing system should ideally fulfill, we will now turn to a description of price and rate structures actually employed. Attention will also be paid to the political decision process that results in the actually employed rate structures, since these are crucial for understanding how and why actually employed structures came into being.

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<sup>11</sup> We know from economic welfare theory that if this condition is not satisfied, water tends to be overused by those sectors adding relatively little to economic output, resulting in economic inefficiencies and wastage.

Practically, the water bill of a household or a firm consists of two parts. One part is unrelated to the actual amount of water used (a flat fee), and one part is either indirectly or directly related to the amount of water used (a rate). In addition, there may be one-time charges that have to be paid for, for example, being connected to the network. The flat fee may be variable in that it may be related to, for example, the number of persons per household or the size of the house. Rates can be constant, but they can also increase or decrease with the amount of water being used. Table 2 contains these elements of the water bill and indicates how the respective elements meet the requirements that were previously discussed.

< Insert Table 2 around here >

What stands out from the Table is that many requirements are mutually exclusive. Therefore, an optimal price and rate structure almost by definition should consist of both fees (either fixed or variable) and rates (which may be non-constant). The resulting structure is influenced by several factors. First, different groups involved (i.e. suppliers, consumers, firms, and the government) in the process of developing a pricing system have different and often opposite interests, as well as different bargaining power. This points at the importance of considering rate structures as the outcome of a political bargaining game between players with different interests and powers. A declining rate structure may, for example, be the outcome of large firms that often have substantial bargaining power. Secondly, the resulting pricing system will depend on the relative weight of the various requirements and may vary between states or countries, as well as over time. Equity considerations may, for example, be of minor importance in advanced economies, while the urgent need for efficient use of water has risen over time and differs strongly between countries. Also, intergenerational equity considerations are more important for groundwater than for surface water, given the exhaustibility of groundwater.

### 2.3.2 Pricing of water; practice in the OECD

This section will be concerned with a discussion of actual pricing policies being used in the OECD countries, observed trends in pricing practices, and progress being achieved and still being required toward the goals of efficient, effective and equitable water pricing. The last decade can best be characterized by a growing awareness in the OECD of an integrated management of the scarce amount of available water, not only focusing on cost-effective supply but also on affecting demand. This has resulted in relatively strongly increasing prices

of water, increased metering, more extensive use of increasing block-tariffs, higher charges for waste-water disposal, an increased willingness to use the price-mechanism to achieve social, economic and environmental goals, and a change in the role of the government that focuses more and more on regulating instead of being the main provider.

Nevertheless, price and rate structures employed in OECD countries still vary a lot. Although an extensive discussion of actual structures is beyond the scope of the paper, some examples may be illustrative. In Amsterdam and parts of Rotterdam, household use is not metered and the water bill correspondingly only consists of a flat fee. This flat fee depends only on, at best, very crude proxies for water use like the total number of rooms, the total area of the house, or the number of members of the family. Within Belgium, Flanders has a decreasing block schedule, most users in Wallonia have an increasing block schedule, while Brussels has a flat rate structure (see OECD (1998; Table 6) for a more extensive comparison of currently employed structures). Despite the observable differences, trends are towards more economically efficient systems providing better incentives for conservation. But the changes are slow and traditions are found to be persistent.

## **2.4 Policy issues**

In this section, we first set out the reasons for the need for government intervention. We then discuss various policies that can be employed by the government to alleviate market failures.

### **2.4.1 The need for government intervention**

The need for government intervention in the process of supplying water originates in various sources. Firstly, the market has some characteristics of a natural monopoly. The investments required to build and maintain the network needed to supply the water are so large that two networks cannot profitably be exploited at the same time. This yields the supplier market power and therefore requires regulation. Secondly, water is an essential good for human life that may strongly affect human's health. A role for the government therefore exists in taking care that all people are supplied with the minimum requirements of high-quality potable water. In Section 2.1, we saw that water is a common pool resource. One solution to overcoming the problems associated with the tragedy of the commons is to privatize the good and to create a market. Assigning property rights should in this view result in owners of the goods to care properly for the resource and in accordance with social optimality. There are however several flaws to this argument. Some problems that may arise are related to the

Especially low-income households may start experiencing budgetary problems upon introduction of taxes.<sup>12</sup>

#### 2.4.2.2 Subsidies

We can distinguish various kinds of subsidies. Subsidies may, for example, be granted to firms and households investing in water conservation technologies. There are however also many implicit subsidies. Any price-structure that does not satisfy the criterion of full cost recovery implicitly grants a subsidy to the user of water. From a theoretical point of view, the use of subsidies to advocate efficient use of water is inferior to the use of taxes. Although subsidies may be effective in reducing water demand on a firm level, total demand may will be sub-optimally high, since the subsidy may keep firms alive that could not survive under the imposition of a tax (e.g., Baumol and Oates (1988)). Nevertheless, the instrument of subsidies has intensively been used in the water-industry (e.g., OECD (1997)). Recent studies strongly advocate subsidy removal or reform (OECD (1997)).

#### 2.4.2.3 Regulation / Technical Intervention

A third way in which the government could affect water use is by regulation. Given the characteristics of the industry, government regulation seems unavoidable. First, the industry being a natural monopoly requires regulation to avoid the abuse of monopoly power. Secondly, health considerations require the imposition of high quality standards and efforts aimed at controlling whether these standards are met. Thirdly, regulation of the dumping of waste-water by industries is needed, etc. Given the huge investments required for technological improvements and the installation of networks, a role for the governments seems granted.

#### 2.4.2.4 Providing information

Lack of information seems to be a major problem with respect to water use. Consumers often do not know how much they pay for water, nor do they know how much water they use. There also seems to be a limited awareness of the scarcity of water and potential future

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<sup>12</sup> See for example a recent discussion in the Netherlands, where the proposal of an increased Value Added Tax on water was discussed in the parliament.



problems with its provision.<sup>13</sup> Campaigns may therefore be an effective tool to increase the public's awareness of problems with the provision of water and thereby to reduce water demand. Given the limited knowledge on water prices, policies aimed at reducing demand by increasing taxes are bound to fail unless accompanied by campaigns.

#### 2.4.2.5 Privatization and fostering competition

At least parts of the sector supplying water have the characteristic of a natural monopoly (due to huge investments required to build the network). The potential for introducing more competition has recently been investigated and there is some experience with actual implementation in, for example, the United Kingdom. The aim of fostering competition is to reduce inefficiencies that are argued to exist in the process of supplying water. There is some evidence that these inefficiencies are substantial (e.g. Dijkgraaf et al. (1997)). Introducing competition in the production and cleaning of water may reduce these inefficiencies.<sup>14</sup>

Some peculiar features of the water industry raise some doubts on the scope for privatization, deregulation, and the effectiveness of fostering competition. First, there is hardly any discussion that the network used to transport water can best be provided and maintained by the government. Secondly, high quality of water is essential. Privatization and deregulation should therefore be accompanied with strict control of water quality. This is the more necessary since producers of water will usually transport water via the same network implying a risk of free-rider behavior if quality control is not performed before water is transported to the consumers.

### 3. Conclusions and future research

Water can be considered as an economic good. Although it has some particular characteristics, studying its supply and demand characteristics is a prerequisite for developing useful policies aimed at a sustainable use of the most fundamental constituent of life. In this paper, we argued that there is in principle supply of and demand for water of different

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<sup>13</sup> In the Netherlands, suppliers have tried to enhance the public's awareness of their use by distributing forms that users were asked to deliberately fill out (every week) and by at the same time providing information on average use of all households, and potentials to save on water use.

<sup>14</sup> According to estimates for the Netherlands, savings are possible in the range of 6-15 percent in the production of potable water, and 8-30% in the cleaning of waste water.

qualities. In many countries, the current situation is one in which the supply of water for private use is uniform in quality. Technological developments make it possible to supply water of different qualities. There may be substantial welfare gains from the creation of such a dual system of water supply. Future research may aim at studying the issues that arise in creating such a dual system of water supply, both from an economic and a technological point of view. It is interesting to investigate the welfare effects of a switch to such a system, both theoretically and empirically. Empirical evidence is needed for such an exercise on demand elasticities of different qualities of water, costs of developing a system of dual piping, etc. Other interesting evidence on demand may be obtained from detailed case studies in which relevant institutions, price and rate structures, policies aiming at increasing the sustainability of water use, and demand are compared between different cities. Meta-analysis may provide a useful tool to perform these studies and to come up with policy guidelines aimed at fostering sustainable water use.

## Appendix A. Theoretical derivations of producer- and consumer demand for water

In this Appendix, we will show how producer- and consumer demand for water can be derived from standard profit- and utility maximizing behavior, respectively.<sup>15</sup> The demand for water from producers derives from their needs associated with the production of goods. We can distinguish four types of demand, each with its own demand-elasticity (see Table A.1).

*Table A.1 Producer Demand functions*

	<i>Some input fixed</i>	<i>All inputs flexible</i>
Output fixed	Short-run conditional demand	Long-run conditional demand
Output flexible	Short-run unconditional demand	Long-run unconditional demand

Demand is assumed to be ultimately derived from the producer's goal to maximize profits by optimally choosing the amount of inputs to be used (we only consider the case in which firms operate in a perfectly competitive environment implying that both the output and the input prices are given). This goal can be formulated as

<sup>15</sup> This Appendix contains standard information on producer- and consumer behavior. It is added for those readers that are not familiar with this theoretical approach to deriving demand and the derivation of price and income elasticities from the demand equations resulting from optimizing behavior.

$$\max_{x_1, \dots, x_N} \pi = py - \sum_{i=1}^N w_i x_i \quad \text{s.t.} \quad y = f(x_1, \dots, x_N)$$

where  $p$  is the output price,  $y$  is the volume of output,  $w$  is the input price, and  $x$  is the volume of inputs. The first-order conditions corresponding to this problem are

$$p \frac{\partial f}{\partial x_i} - w_i = 0$$

This equation tells that firms will use an additional input until the marginal benefit equals the marginal cost of doing so. We will now structure the problem somewhat more by making the production function  $f$  more explicit. We take for the sake of illustration a Constant-Elasticity of Substitution (CES) production function<sup>16</sup>

$$y = \left[ \sum_{i=1}^N a_i x_i^\rho \right]^{\frac{1}{1-\rho}}$$

where the elasticity of substitution is defined as  $\sigma \equiv \frac{1}{1-\rho}$ . The conditional demand for input  $i$  can now be determined as

$$x_i = \frac{y^{1-\rho} \left( \frac{w_i}{a_i} \right)^{-\sigma}}{\left[ \sum_{j=1}^N a_j \left( \frac{w_j}{a_j} \right)^{-\sigma \rho} \right]^{\frac{1}{1-\rho}}}$$

The determination of the conditional demand-functions boils down to solving a cost-minimization problem. From this expression, the own price-elasticities, the cross-price elasticities, and the output-elasticities of demand can easily be derived which are defined as

$$\varepsilon_i^i = \frac{\partial x_i}{\partial w_i} \frac{w_i}{x_i}, \quad \varepsilon_j^i = \frac{\partial x_i}{\partial w_j} \frac{w_j}{x_i}, \quad \text{and} \quad \varepsilon_y^i = \frac{\partial x_i}{\partial y} \frac{y}{x_i}$$

respectively. Along similar lines, we can determine the unconditional demand for input  $i$  as

$$x_i = \frac{\mu^{1-\mu} p^{1-\mu} a_i^\sigma w_i^{-\sigma}}{\left[ \sum_{j=1}^N a_j^\sigma w_j^{-\sigma \rho} \right]^{\frac{\rho-\mu}{\rho(1-\mu)}}$$

from which own- and cross-price elasticities of demand can be determined. So far, we have only considered long-run demand. The determination of short-run demand again proceeds along the same lines, but now producers are not able to determine the volume of all inputs (so

<sup>16</sup> In the special case in which  $\rho \rightarrow 0$  the production function boils down to a Cobb-Douglas production function that is characterized by an elasticity of substitution equal to one.

some  $x_i$ 's are taken as given by the producer). We refer to Baumann (1998) for a discussion of short-run demand, as this is beyond the scope of this Appendix.

The water-demand from consumers is derived from a utility-maximization problem in which consumers maximize their utility subject to a budget constraint by optimally choosing the amount of goods to be consumed, given the income and prices of the goods. In general terms, such a utility function looks like

$$\max_{C_1, \dots, C_S} U = \left[ \sum_{i=1}^S a_i (C_i - \bar{C}_i)^\rho \right]^{1/\rho} \quad s.t. \quad \sum_{i=1}^S C_i P_{Ci} < I$$

where  $U$  is the utility function,  $C_i$  is the consumed amount of goods of type  $i$ ,  $P_{Ci}$  is the price of good  $i$ ,  $\bar{C}_i$  is the subsistence requirement of consumption,  $I$  is income, and  $a_i$  is a distribution parameter. In the absence of subsistence requirements,  $1/(1-\rho)$  is the elasticity of substitution between goods from different sectors. Table A.2 gives an overview of the utility functions that are usually distinguished in the literature., where the functions are characterized by specific parameter values.

Table A.2 Consumer utility functions

	$\rho \rightarrow 0$	$\rho \neq 0$
$C_i = 0$	Cobb-Douglas utility	CES
$C_i \neq 0$	Stone-Geary utility	CES

Formulating the Lagrangian corresponding to the consumer's optimization problem and performing standard optimization yields demand for consumption good  $i$  as a function of prices

$$C_i = \bar{C}_i + \left( \frac{P_{Ci}}{a_i} \right)^{\frac{1}{\rho-1}} \frac{\left[ I - \sum_{j=1}^S P_{Cj} \bar{C}_j \right]}{\sum_{j=1}^S P_{Cj} \left( \frac{P_{Cj}}{a_j} \right)^{\frac{1}{\rho-1}}}$$

From this demand equation, own- and cross-price elasticities and the income elasticity of demand can be derived as

$$\varepsilon_i^i = \frac{\partial C_i}{\partial P_{Ci}} \frac{P_{Ci}}{C_i}, \quad \varepsilon_j^i = \frac{\partial C_i}{\partial P_{Cj}} \frac{P_{Cj}}{C_i}, \quad \text{and} \quad \varepsilon_I^i = \frac{\partial C_i}{\partial I} \frac{I}{x_i}$$

For water-demand it seems realistic to assume the subsistence requirement to be relatively large and to assume a relatively poor substitutability between other goods.

In the discussion so far, we mainly restricted attention to the special case in which the elasticity of substitution between any pair of consumption goods or inputs is constant and equal for any pair. Of course, optimization problems could be made more complex, allowing for all kinds of nested functions, but a discussion of those issues is beyond the scope of this Appendix in which we only aimed to give some feeling on how elasticities can be derived from a theoretical framework.

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Table 1. Overview of household demand elasticities (for household demand)

Study	Details of study, model and estimation	price elasticity	income elasticity	sample
Hewitt and Hanemann (1995)	D/C choice model	-1.59	0.15	US panel
Howe and Linaweaver (1967)	OLS	-1.57		
Danielson (1979)	OLS	-1.38		
Deller et al (1986)	2SLS	-1.12		
Grima (1972)	cross-section	-0.75 (w)		Urban demand in eastern Canada
Herrington (1982)	time-series (1962-1980)	-1.07 (s)		
		-0.3		Industrial consumption in England and Wales
Nieswiadomy et al. (1989)		-0.3/-0.9		US panel
Gallagher et al. (1981)	pooled cross-section and time series	-0.26 (s)		137 households in Queensland (Australia)
		-0.75 (l)		
Martin et al. (1983)	pooled cross-section and time series	-0.256		2159 households in Arizona (USA)
Hanke and De Maré (1982)	pooled cross-section and time series	-0.15		69 domestic residences in Malmö (Sweden)
Laukkanen (1981)	time series (1970-1978)	-0.11		Municipal demand in Helsinki (Finland)
Howe (1982)	cross-section	-0.06 (w)		Residential use in Eastern and Western USA
		-0.57 (s; east)		
		-0.43 (s; west)		
Thomas et al. (1983)	cross-section	-0.04 (i)		315 households in Perth (Australia)
		-0.31 (x)		
		0.18		

Sources: OECD (1987, Table 6) and the various references. Symbols: (i) in-house demand, (x) ex-house demand, (s) short run elasticity, (l) long-run elasticity

Table 2. Scores of different price structures on various criteria

Criterion	One-time payment	Fixed Fee	Variable fee	Constant	Rates Increasing	Decreasing
Revenue stability		++	+	-	-	-
Equity	-	-	-		++	--
Efficiency - marginal cost pricing	--	--	+	++	++	++
Efficiency - incentives					++	--
Administrative feasibility	++	++	+	-	-	-
Administrative efficiency	+	++	+	-	--	--

Note: '++' means that the criterion is well matched, while '--' means that the criterion is not matched at all.